SUBPIXEL SNO W-COVERED-AREA AND SNOW GRAIN SIZE FROM M IXTURE ANAL YSIS WITH AVIRIS DATA

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INTRODUCTION

Snow-covered-area (SCA) and snow grain size arc crucial inputs to hydrologic and climatologic modeling of alpine and other seasonally snow-covered regions. SCA is necessary to parameterize energy budget calculations in climate models, to determine in which regions point snowmelt models arc to be run for distributed snowmelt modeling efforts [Barrington et al., 1995] and to provide a basis from which estimates of snow water equivalent (SWE) may be made [Martinec and Range, 1981]. Snow grain size, SWE and snow impurities determine the spectral albedo of snow, which controls the net solar flux at the snowpack surface. Snow albedo is of the utmost importance in snowmelt modeling, yet the difficulty with which grain sire, SWE, and impurities arc mapped has left the spatial distribution of snow albedo in alpine catchments poorly understood [Kirnbauer et al., 1994]. The Airborne Visible/lnfrared Imaging Spectrometer (AVIRIS) has been used to estimate subpixel snow-covered-area and snow grain size independently [Nolin, 1993]. In this paper wc present a technique which improves estimates of both snow parameters by treating their mapping simultaneousl y.

BACKGROUND

The spectral signature of snow is characterized by near- 100% reflectance in visible wavelengths and moderate reflectance in NIR wavelengths. While visible reflectance is strongly affected by absorbing impurities and shallow snow, and nearly independent of grain sire, NIR reflectance is primarily dependent on grain size with reflectance decreasing as grain size increases. Snow reflectance is most sensitive to grain size in the wavelength range 1.0- 1.3μm, which spans the diagnostic ice absorption features at 1.03μm and 1.26pm. The large spectral contrast of snow reflectance is duc to a variation of seven orders of magnitude in the absorption coefficient of icc at wavelengths from 0.4- 2.5μm [Dozier, 1989]. The above relationships arc those exploited in grain size mapping [Dozier and Marks, 1987; Nolin, 1993].

Alpine snow-covered regions frequently exhibit large grain size gradients, correlated strongly with altitude and aspect. When snow is deposited on the surface, grains immediately begin the modifying process called 'metamorphism'. Initially, grain size decreases when thermodynamically-unstab]c dendritic crystal branches arc destroyed through collisions and water vapor transfer. Larger grains then grow at the expense of smaller grains via vapor transport and melt-refreeze. Because metamorphism is faster at higher temperatures and under larger temperature gradients [1 .angham, 1981], the absorption of short-wave radiation at the snowpack surface and the transfer of longwave radiation at and below the snowpack surface play dominant roles in grain modification. Alpine regions thcu exhibit grain size gradients driven by aspect and elevation with largest grains at low elevations on southerly aspects and smallest grains at high elevations on northerly aspects. The sensitivity of snow spectral reflectance to grain size translates these grain size gradients into spectral gradients.

in *Painter et al.* 1995, wc demonstrated that, duc to these grain size and spectral gradients, multiple snow endmembers spanning the imaged domain's grain size gradient arc required to accurately estimate subpixel SCA with spectral mixture analysis. Succinctly put, mapping subpixel SCA requires knowledge of the spatial grain size distribution. Estimates of grain size have been made previously from optical data, yet these have relied on the assumption of pure-snow pixels [Dozier and Marks, 1987; Nolin, 1993]. The propensity of mixed pixels in alpine- and forested-regions makes such an assumption suspect, and snow grain size estimates for such mixed pixels will be contaminated. Hence, mapping grain size distribution requires knowledge of subpixel SCA distribution. It follows, then, that the problems of estimating subpixel snow fraction and snow grain size are intimately lied.

METHODS AND DATA

We present here a technique which simultaneously estimates subpixel SCA and snow grain size by optimization of mixture anal ysis with multiple snow endmembers. From AVIRIS data collected over Mammoth Mountain, CA on April 5,1994, a suite of snow image endmembers corresponding to the region's grain size range were extracted. Mixture models with fixed vegetation, rock, and shade image endmembers were applied with each snow endmember. For each pixel, the snow-fraction estimated by the model with least mixing error (RMS) was selected to produce an optimal map of subpixel SCA [Figure 1]. Grain size for the snow within each pixel was then estimated by the grain size of the selected snow endmember [Figure 2]. This step bypasses the pure-snow pixel assumption by producing a snow grain size estimate for any permutation of snow, vegetation, rock, and shade, provider-t that the snow-fraction is non-zero.

Numerical simulations demonstrate that in the simple linear mixing case [Adams et al., 1993], the technique is very accurate at estimating subpixel SCA and snow grain size for any permutation of surface constituents, provided that the non-snow endmembers are well-known and the snow fraction is non-zero. To validate image results, optimal subpixel SCA from AVIRIS data were compared with coregistered aerial photos and individual model SCA maps, and grain size results were compared with point size distributions estimated by stereology of field snowpack samples [Davis et al., 1987] and contrasted with AVIRIS results using techniques incorporating the pure-snow assumption [Nolin, 1993].

DISCUSSION

Results demonstrated that the technique is accurate at estimating subpixel SCA, and appears to be more accurate at estimating snow grain size than pure-snow assumption techniques, particularly in forested and patchy-snow areas. Limitations do exist though when applying the technique to AVIRIS data. We mentioned above that numerical simulations demonstrated that the technique is very accurate in the linear mixing case; however, in forested and thin-snow areas, mixing is non-linear. Errors are then introduced into the estimates of SCA and grain size. Additionally, in using image endmembers, the number of snow endmembers is limited (e.g. six snow endmembers in this work) whereby the resolution of grain size will be coarse. Further work needs to *i)* evaluate non-linear mixing in alpine regions, *ii)* incorporate techniques from the literature to compensate for non-linearity in vegetated areas, *iii)* continue with the development of a technique to map thin/impure snow, and *iv)* incorporate snow reference endmembers at far greater grain size resolution for grain size estimates. The incorporation of reference endmembers will require the. elimination of discrepancies between modeled spectral signatures and those derived from AVIRIS.

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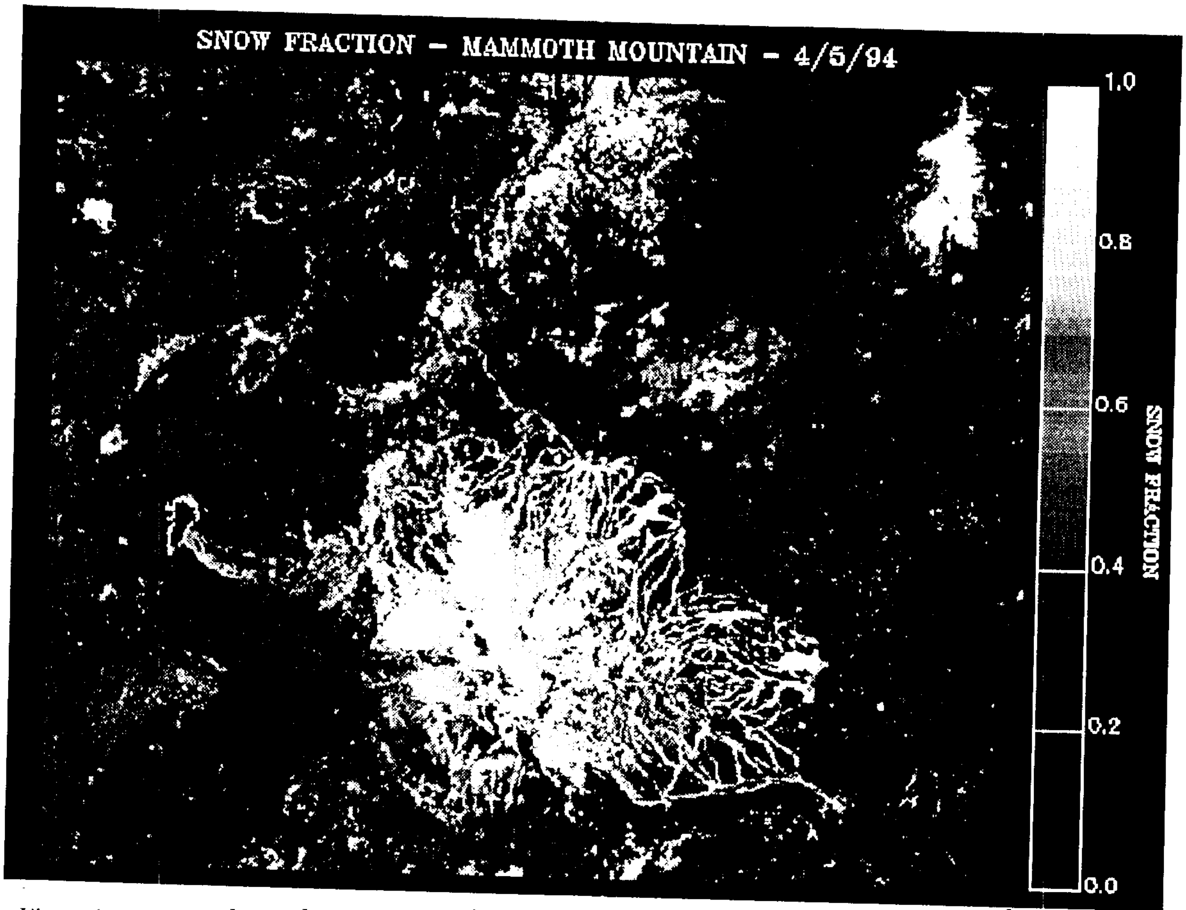

Figure 1. AVIRIS-derived subpixel snow fraction at Mammoth Mountain, CA, optimized with multiple snow endmembers.

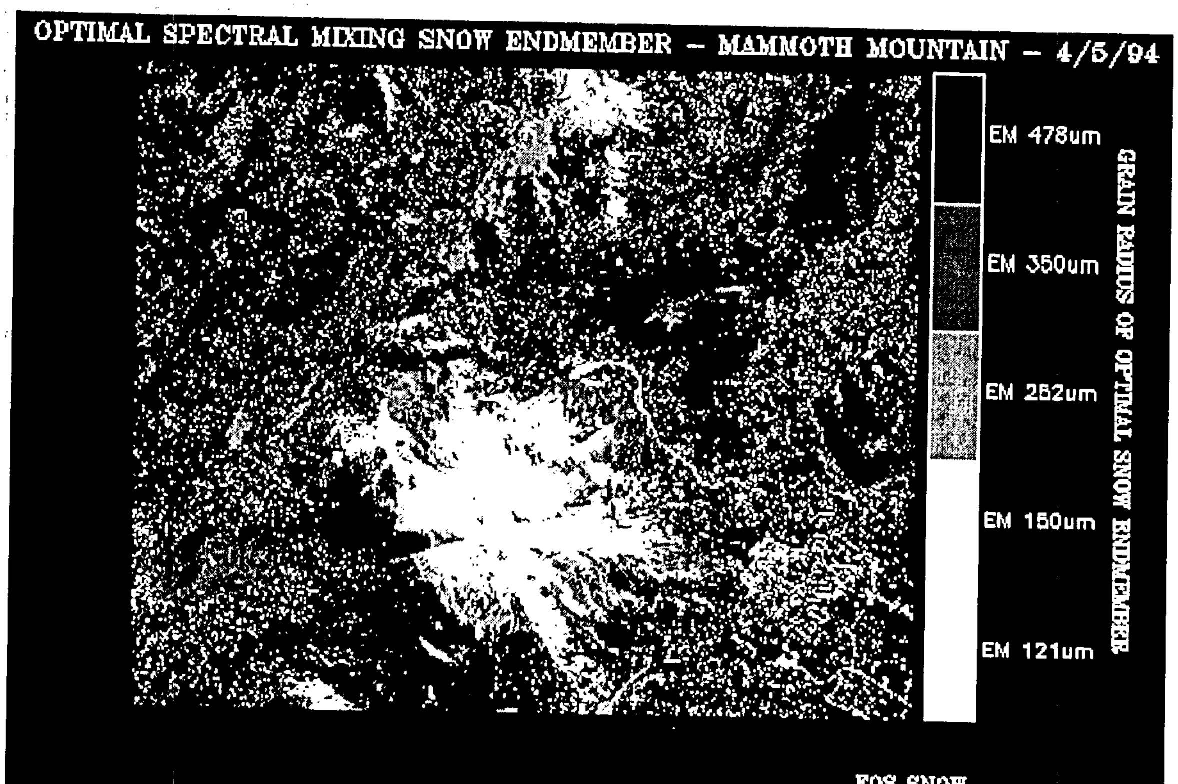

Figure 2. Map of snow endmember used and grain size estimate at Mammoth Mountain, CA from AVIRIS.